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PRODUCTION OF PLATES OF FIBER COMPOSITES  
BY SOLIDIFICATION, FORMING AND A  
COMBINATION OF BOTH

Author: Lt. W. L. Marsh, USN  
Thesis Supervisor: Dr. J. Wulff  
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Thesis  
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PRODUCTION OF PLATES OF FIBER COMPOSITES BY SOLIDIFICATION,  
FORMING AND A COMBINATION OF BOTH

by

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Production of Plates of Fiber Composites by Solidification,  
Forming and a Combination of Both

by

WILLIAM L. MARSH, LT, USN

Submitted to the Department of Naval Architecture and Marine Engineering on 17 May 1968 in partial fulfillment of the requirements for the Master of Science Degree in Naval Architecture and Marine Engineering and the Professional Degree, Naval Engineer

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ABSTRACT

The purpose of this investigation was to determine the feasibility of unidirectionally solidifying the  $Al_3Ni$  eutectic in plate form. The plates solidified displayed good fiber formation but poor fiber alignment. Tensile strengths achieved were nearly twice that of the as cast alloy but only half of strengths achieved in cylindrical specimens. Plates with thickness to width ratios of 2, 25, and 75 were grown and tested. The hot pressing of  $Al_3Ni$  plates was found to increase the strength to more than twice that of the as cast alloy. However, it was found that the bond between the plates was weak to the extent that the layers could be peeled apart.

Thesis Supervisor: Dr. J. Wulff

Title: Professor of Metallurgy



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## I. INTRODUCTION

In the continued search for materials possessing high strength to weight ratios, increasing attention is being given to the development of composite systems. The idea of combining materials having high strength, but which also have high density or low ductility with materials having lower strength, coupled with good ductility and low density, indeed seems promising.

Glass reinforced plastic has proven itself to be a practical and reliable material. In the area of metallic fiber composites, research is being performed on fabrication methods such as imbedding high strength rods or fibers in a metallic matrix, liquid metal infiltration, solid or liquid phase sintering, and direct growth of a composite from a melt. The last technique mentioned, direct growth, is the subject of this paper.

Production of a fiber or plate reinforced composite from a melt can be performed by unidirectional solidification of eutectic-like alloys. Mollard and Flemings (1) note that fully eutectic-like structures can be obtained over a range of compositions. They obtained well-formed fiber composites in Pb-Sn alloys at 12.6 wt. % Pb where the eutectic composition is 26 wt. % Pb. This investigation is confined to a eutectic composition aluminum-nickel alloy. Other eutectic alloys previously employed in unidirectional solidification experiments include Cu-Cr, Al-Cu, Ni-Mo, Cb-C, and Ta-C (2). In these alloys the two phases exist as a matrix surrounding aligned lamellae, platelets or rods.



The alloy to be considered here is the Al-Ni eutectic composition of 6.13 wt. % Ni (3). The directionally solidified eutectic has been shown to behave as a whisker reinforced composite in providing a 350-400% increase in tensile strength over the as cast material (tests made with the load axis parallel to fiber alignment) (4). When containing 10-11 volume % fibers the material has been shown to obey the rule of mixtures, i.e. 10% fibers ( $\sigma_{ult} = 500,000$  psi) plus 90% matrix ( $\sigma_{ult} = 5,000$  psi) results in an overall strength of approximately 50,000 psi (4). In addition, it has been shown that the microstructure of this alloy exhibits exceptional stability at elevated temperatures. Such stability is not to be found in composites formed by imbedding vapor grown whiskers into metal matrices (2). The size and spacing of the  $Al_3Ni$  rods has been found to vary with solidification rate according to a relationship,

$$\lambda^2 R = \text{constant}$$

where  $\lambda$  is fiber spacing and  $R$  is growth rate (8). The creep behavior is better with small rod spacing (faster growth rate) (2). This is due to the pinning of dislocations in the matrix by the rods. Notched impact toughness experiments indicate the material is promising in this area. The toughness noted was accredited to the crack arresting abilities of the soft aluminum matrix (2).

The purpose of the present investigation was to determine whether good fiber alignment could be attained when the alloy is





directionally solidified in plate form. The degree of alignment is most important in strength considerations. George, Ford, and Salkind (4) have tabulated results which show a marked decrease in strength with small ( $5-10^\circ$ ) misalignment of load and fiber axes. As a natural second step, the bonding characteristics of the unidirectionally solidified plates also required study.



## II. PROCEDURE

### Initial Melt

To obtain the material used in this investigation three melts of approximately 1,100 grams each were made. The melts were made in air in a graphite crucible set into an induction heater. To accelerate the operation the aluminum (99.99%) was added as chunks about 1.5 inch square while the nickel (99.999%) was rolled to a foil and added as strips. The molten metal was poured at 900°C. as measured by an optical pyrometer. Since this temperature is well below the melting point of nickel (1,450°C.) special care had to be taken to ensure complete solution and diffusion of that constituent. To this end, the melt was held at 900°C. until the nickel strips disappeared. The mixture was then stirred thoroughly with a graphite rod, allowed to equilibrate for fifteen minutes, and stirred again immediately prior to pouring. The melt was cast into the graphite mold described in the Appendix and allowed to cool in air.

### Directional Solidification

All directional solidification was carried out using a specially constructed furnace described in the Appendix. The objectives incorporated into this apparatus were threefold:

1. To regulate the speed of the solid-liquid interface by controlling the speed of the moving heat source.



2. To direct heat flow downward by providing a heat sink.
3. To reduce chemical reaction at the skin of the molten plate by maintaining an inert atmosphere.

To directionally solidify a plate 0.75 in. thick by 1.5 in. wide one of the as cast ingots (with 0.5 in. cut from the top to allow for expansion) was placed into the same graphite mold used in casting. The mold was inserted into the furnace tube which was evacuated and flushed with argon (welding grade) in three cycles. With the tube under a slight positive argon pressure, the heater was brought to 700°C. When the ingot was molten, circulating water (50°F.) was started through the chill and the furnace withdrawal (6.5 cm/hr.) begun.

The growth of plates measuring 0.040 in. thick by 1.0 in. wide required some procedural changes. For this operation graphite inserts were machined to fit inside the 0.75 in. x 1.5 in. slot in the mold. These inserts are described in the Appendix. A piece of an ingot was cut so as to rest upon these inserts. This piece was split in half to allow the free movement of air from the slots formed by the inserts. The furnace was brought to 700°C. with the tube under a vacuum. When a molten state was achieved, 5 to 10 psi of argon pressure was introduced to place a head on the molten metal and break the oxide skin allowing the metal to flow into the narrow slots. Then chill water was introduced and furnace withdrawal started.

In both cases mentioned above, the as cast  $\text{Al}_3\text{Ni}$  was cleaned with abrasives and bathed in a 1.0% HF solution immediately prior to insertion into the furnace.





### Hot Pressing

Directionally solidified plates with their growth directions aligned were pressed together in a hydraulic press at 900°F. Pressures of 5,000, 7,500, and 10,000 psi (based on dimensions prior to pressing) were employed. The platens in the press were made of stainless steel and were cleaned and painted with a colloidal suspension of graphite in water prior to each use. The press is described in the Appendix. The plates themselves were cleaned immediately prior to pressing in the following solution:

Chromium trioxide (crystals).... 20.3 gm.

H<sub>2</sub>SO<sub>4</sub> (95-98%)..... 50.8 ml.

Water.....200.0 ml.

The bath was given at 60°C. for 10 minutes.

The plates were put under pressure which was maintained as the temperature increased. When 900°F. was attained, the pressure maintenance was stopped. After 30 minutes at temperature, the pressure was dropped and the laminated plate allowed to cool in air.

### Tensile Tests

Both single and laminated plates were tested under tension at room temperature. Standard, circular tensile specimens were made from the 0.75 x 1.5 in. plate while flat specimens were made from the thinner plates. The circular specimens were 2.25 in. long with a 1.0" gage length and a 0.1 in. gage diameter. The flat specimens were 5.0 in. long and 1.0 in. wide. The gage section measured 2.5 in. by 0.5 in. The strain rate employed in all tests



was 0.01 in/min. Photographs of the fractured specimens may be seen in Figure I. All tensile testing was performed on an Instron testing machine.

#### Specimen Examination

Microspecimens of single and laminated plates in both the whole and fractured condition were made. Longitudinal and transverse section photographs were taken and included in this report. All microspecimens were mounted in bakelite, polished on silicon carbide paper and diamond polishing wheels, and etched in a 1.0% HF solution for periods of 5 to 40 seconds.



### III. RESULTS

The casting process produced well-shaped, rectangular ingots measuring 0.75 x 1.5 x 7.75 inches (after removal of the feed riser). The surface appearance was smooth with minor amounts of loose graphite adhering. In all cases, the metal was removed simply by inverting the mold and allowing the ingot to slide out. There was a problem of entrapped gas. Bubble cavities were found at the ingot centerline near its top. These cavities were large, but were not noticeable on the metal surface.

After unidirectional solidification, the surface appearance of the ingot was the same as above except at the top where the metal had dropped to fill the bubble cavities leaving unsupported wrinkles of brittle oxide skin. No bubble cavities were found. Internally, microscopic examination revealed the formation of  $\text{Al}_3\text{Ni}$  fibers in an aluminum matrix (see Figures II-V). The fibers were well-formed but appeared to have a general tendency to misalign with the growth direction by fanning toward the plate's edge while growing upward (see Figure II). During the unidirectional solidification of the large ingot a second, smaller specimen was unintentionally made. Some of the liquid metal found its way through the small gap between the bottom plug and the wall of the mold. The result of this "leak" was a foil-like piece of Al-Ni eutectic which measured 0.75 x 2.25 inches and varied from 0.007 to 0.010 in. in thickness. A microspecimen of this material showed



it to be composed of the fiber-matrix combination mentioned above (see Figure III). In both instances mentioned, examination showed the fiber formation to exist in a form which did not change over the length of the plate. The fiber length, spacing, and thickness all remained essentially constant. There was a large number of grains as made evident by sudden changes in fiber orientation seen in the longitudinal sections. In the transverse sections the  $\text{Al}_3\text{Ni}$  rods appeared as small, regularly spaced, dots in the light background of the matrix.

The same description applies to the 0.040 x 1.0 x 6.0 in. plates. As noted in the section on procedure, these plates were formed by forcing liquid metal down two slots in graphite. When extracted from the mold the plates appeared as two closely spaced appendages protruding from the feed ingot. In some cases, the metal did not cover all of the upper surface of the slot and a neck resulted in the width of the finished plate. These areas were cut away and discarded.

The important point to note in the descriptions above is the fanning out of the fibers toward the thin edge of the plates, that is, in the plane of the wider edge. This was noted in all plates and will be discussed later.

In the hot pressing operations large amounts of deformation were observed and are recorded in Table I for two lamina plates. Note that the plates expanded much more in width (perpendicular to the





Table I

## Deformation from Hot Pressing

<u>Pressure</u> <u>(psi)</u>	<u>% Increase</u> <u>in Length</u>	<u>% Increase</u> <u>in Width</u>	<u>% Decrease</u> <u>in Thickness</u>
5,000	4	32	32
7,500	6	60	41
10,000	8	87	44

fibers) than they did in length (parallel to the fibers). Under the microscope the hot pressed bond appeared as a thin, wavy line in the longitudinal and transverse view (see Figure IV). There were some voids noted along the bond line. The two lamina plates held together well so, in an effort to obtain a plate thick enough to provide threaded, elevated temperature tensile specimens, a fourteen lamina plate was tried. At the end of the first 30 minute press at 7,500 psi., the thickness had been reduced from 0.560 in. to nearly 0.200 in. - a 64% reduction. However when air quenched, the plates separated at the center bond. Pressing again at 7,500 psi. further reduced the thickness to 0.093 in. Total expansion in width had, by this time, exceeded 500%. Attempts at machining this material showed the bonds between plates to be wholly unsatisfactory. It proved to be an easy matter to manually peel one layer of metal from another, be it a two or fourteen layer plate (see Figure V).



The fiber-matrix combination appeared to be undisturbed by the hot pressing. There was no rod coarsening noted. The morphology of the individual plates was constant right up to each bond.

To describe the results of the tensile tests, Table II is provided.

Table II

Tensile Test Results

<u>Source of Sample</u>	<u>Type of Specimen</u>	<u>Ultimate tensile stress (psi)</u>
0.75 x 1.5 in. plate		
#1	circular	23,000
#2	circular	21,200
#3	circular	23,000
#4	circular	22,300
0.04 x 1.0 in. plate		
#1	plate	20,800
#2	plate	22,800
#3	plate	26,500
Thin foil (0.010 in.)	plate	24,600
Hot Press - 2 lamina		
#1 (5,000 psi)	plate	29,800
#2 (7,500 psi)	plate	30,500
#3 (10,000 psi)	plate	29,300



The material appeared to fail by a shear mechanism in all cases. In the plate specimens fracture was always initiated by the appearance of a crack at the radius at the end of the gage section. Once begun, the crack would propagate slowly until total failure occurred. In the circular specimens failure occurred as a sliding separation along a plane approximately  $45^{\circ}$  from the specimen axis.





#### IV. DISCUSSION OF RESULTS

It was found that the growth of Al-Al<sub>3</sub>Ni eutectic composites from the melt in plate form was possible. The Al<sub>3</sub>Ni fibers were well-formed though significant misalignment with the growth direction was observed. Ultimate tensile strengths achieved were greater than reported in the as cast metal but less than reported in work with circular, well aligned specimens. The hot pressing operation showed the material to deform readily, but the bonds achieved were weak. It was also observed that tensile strengths were noticeably higher after hot pressing than before.

The most important result of this investigation was the deficiency found in ultimate tensile strength of the directionally solidified thin fiber plates. Specimens taken from the same master melts and unidirectionally solidified in a cylindrical shape were found, by other investigators (10), to have ultimate strengths of approximately 40,000 psi. The average strength achieved in all single plate specimens was 23,000 psi. Since the material used in both specimen types was identical and growth conditions were essentially the same, it is assumed that the fiber misorientation noted in the plates is the cause of the low strength values obtained.

As noted previously, George, Ford, and Salkind (4) have tabulated results of load axis vs. fiber orientation experiments for Al-Al<sub>3</sub>Ni. In order to correlate the results of this paper and the previous work, an average angle of misorientation of Al<sub>3</sub>Ni



fibers with the growth direction (also the load axis) was measured. To obtain this angular value, a series of photographs was taken at 2 mm. intervals across the width of a 0.75 in. plate. Edge and centerline photos from the plate top, midlength, and plate bottom are shown in Figure II. Since fracture occurred near the plate midlength, the central series of pictures was used to determine the average degree of misorientation. A line was drawn across all 9 pictures. A mean fiber misorientation was determined from a histogram of orientation angles with a five degree interval. The mean value of fiber misorientation from the vertical axis was  $9.5^{\circ}$ . The results of actual tensile strength vs. fiber orientation tests (4) indicate that for an Al-Al<sub>3</sub>Ni eutectic, unidirectionally solidified, with an ultimate strength of approximately 40,000 psi. for complete fiber alignment a strength 23,000 psi. was achieved with  $10^{\circ}$  misalignment. While it is recognized that a statement to the effect that the correlation between the two sets of results is good is inappropriate with only one data point, it is also recognized that the degree of agreement makes further investigation seem warranted.

It does not seem unreasonable to presume that varying amounts of fiber-load axis misorientation within a specimen would be governed by a rule of mixtures. In the accepted application, this rule is used to predict the strength of a multiphase material at a section by apportioning the known strengths of the various phases



according to their volume fractions at the section under consideration. An application wherein the known strengths of groups of misoriented fibers are apportioned according to their volume fractions would seem to be equally valid. Such a rule, if proven, would certainly provide a method for predicting the strength of a composite containing randomly distributed groups of misoriented fibers based on tests of specimens with a high degree of alignment.

The second point to be considered is the reason behind the variation in fiber growth direction. It is recognized that, in a normal eutectic, the two phases grow in a direction perpendicular to the solid-liquid interface under controlled directional solidification conditions (2). Therefore, based on the variance in fiber orientation found, it must be assumed that the interface was not planar during the plate solidification process. The series of photographs of Figure II was used to estimate the actual shape of the solid-liquid interface at the plate top, midlength, and bottom (see Figure VI). To obtain the profiles, the angle of misorientation measured in each photograph was assumed to exist for a distance of 1 mm. to either side of the point examined ( $\frac{1}{2}$  the distance to the next photo). The angles measured in edge sections were assumed to continue 1 mm. into the plate. In cases where two angular values existed in one picture (across a grain boundary) the value on each side was carried 1 mm. to that



side. The profiles were constructed by drawing line segments perpendicular to the growth directions measured. Starting at the left edge of the plate at zero elevation, the segments were drawn to the right with each one beginning at the elevation where the previous segment ended.

With the exception of the plate bottom section where nucleation problems, mold curvature, and growth instabilities act to confuse the picture, the tendency shown is for the center of the interface to extend up into the liquid higher than its level at the edges. The appearance of the profile peak to the right of the plate centerline is accredited to a slight misfit of the inserts in the mold. The gap between mold and inserts represents a large thermal resistance and was visibly wider on one side than on the other. This shape indicates a temperature variation between the edge of the plate and its centerline.

The temperature difference across the plate is felt due to geometric dissimilarity between the flat plate specimen and the circular mold containing it. Reference to Figure IX shows that the conduction path to the plate edge from the external wall of the mold is shorter than the path to the plate centerline. The ratio of the two distances was calculated to be 0.88. The equation

$$\frac{q}{A} = k \frac{dT}{dx} \quad (1)$$

where  $\frac{q}{A}$  = heat transfer/unit area,

$k$  = thermal conductivity

$dx$  = distance between 2 points, and

$dT$  = temperature difference across  $dx$





applies in straight conduction problems (11) and may be written for each of the two conduction paths. Thus,

$$\frac{q}{A}_{\text{long}} = k \frac{dT}{dx}_{\text{long}} \quad \text{and} \quad \frac{q}{A}_{\text{short}} = k \frac{dT}{dx}_{\text{short}}$$

where the conductivities are equal. Assuming

$$\frac{q}{A}_{\text{long}} = \frac{q}{A}_{\text{short}},$$

division of the two equations gives

$$\frac{\frac{dT}{dx}_1}{\frac{dT}{dx}_s} = 1$$

or

$$\frac{dT_s}{dT_1} = \frac{dx_s}{dx_1} = 0.88 \text{ from above.} \quad (2)$$

Considering the external wall of the mold to be an isotherm at  $690^{\circ}\text{C}$ . (allowing  $10^{\circ}\text{C}$ . drop from the furnace wall to the mold) and assuming the centerline of the plate to be at  $630^{\circ}\text{C}$ ., the eutectic temperature (solid-liquid interface at centerline) gives

$$dT_1 = 60^{\circ}\text{C}.$$

$$\therefore dT_s = 0.88 (dT)_1 = 53^{\circ}\text{C}.$$

The calculations indicate a  $7^{\circ}\text{C}$ . temperature difference between plate edge and centerline (molten metal and immediately adjacent



graphite assumed to be at the same temperature). The vertical thermal gradient in the mold resulting from the combination of chill and furnace motion was measured to be  $16^{\circ}\text{C}/\text{cm}$ . Thus a variance of  $7^{\circ}\text{C}$ . between plate edge and centerline would indicate a variance of

$$\frac{7^{\circ}\text{C.}}{16^{\circ}\text{C}/\text{cm.}} = 0.44 \text{ cm.}$$

in the height of the solid-liquid interface between the same two points. The profiles sketched in Figure VI indicate the actual height variation in the interface to be less than the calculations predict. The maximum values shown are 0.23 cm. at midlength and 0.13 cm. at the plate top. It is proposed that free convection is present in the liquid metal and acting to cancel the temperature gradient calculated across the interface.

The pertinent dimensionless parameter in free, thermal convection is the Rayleigh number:

$$\text{Ra} = \frac{L^3 \beta g \Delta T}{\alpha \nu}$$

where  $L$  = characteristic dimension of the system,

$\beta$  = volume coefficient of thermal expansion,

$g$  = acceleration of gravity,

$T$  = temperature difference across  $L$ ,

$\alpha$  = thermal diffusivity of the liquid, and

$\nu$  = kinematic viscosity of the liquid.



Experimental observations have indicated that turbulent convection does exist in systems where the Rayleigh number exceeds a value of  $10^5$  (12). An order of magnitude calculation showed the Rayleigh number for the present system to be in the  $10^7$  to  $10^8$  range. It may therefore be assumed that convection does exist and that it is turbulent in nature. Such convection carrying molten metal up the plate edge into higher temperature regions of the furnace and thence down the plate centerline would indeed act to decrease the horizontal temperature gradient at the solid-liquid interface and, thus, flatten the interface itself.

In the attempts at hot pressing the directionally solidified plates, poor bonds were obtained. This is believed to be due solely to the presence of an oxide layer on the plates. The layer was removed in the acid bath but, no doubt, reformed in the time it took to go from the bath to the press. It may also be assumed that the layer continued to grow during the pressing operations since the specimens were pressed in air at elevated temperatures. This continued growth would tend to offset the splitting of the oxide film caused by the plate's expansion in length and width. Such splitting would, in an inert atmosphere, expose clean metal surfaces from which a good bond could be obtained.

The large variance in plate expansion in width over expansion in length may be attributed directly to the large variance in the



material strength in the fiber growth direction as opposed to its strength perpendicular to the growth direction. Reference (4) cites results which show this variance to be on the order of 37,000 psi. (from 50,000 to 13,000 psi.).

The two plate laminates showed a marked increase in tensile strength (30,000 psi.) over the single plates (23,000 psi.). In a composite system with fibers approximately 1 micron in diameter it is proposed that the fibers act to restrict the motion of dislocations through the matrix. The deformation imposed in hot pressing would create and cause the movement of dislocations which would be subsequently pinned by the fibers. Such a process would serve to work harden the material. This is felt to be the reason for the increase in tensile strength seen in the laminated plates.

The type of fracture seen in tensile tests (crack initiation and slow propagation) attests to the toughness of the material. The fact that the cracks always occurred at the radii at the end of the gage sections where small machining marks were visible seems to indicate that the material is notch sensitive insofar as crack initiation is concerned. However, the crack arresting properties of the soft aluminum matrix (2) seem to work well in limiting the speed of crack propagation.





## V. CONCLUSIONS

1. The growth of Al-Al<sub>3</sub>Ni eutectic composites from the melt in plate form is possible.

2. The strength of the directionally solidified thin plates is dependent directly upon the degree of fiber alignment obtained, with full potential realized only when fiber alignment is nearly perfect throughout the composite.

3. The fiber alignment, being dependent upon the solid-liquid interface shape, is highly sensitive to geometric variations in the directional solidification apparatus which result in thermal gradients transverse to the growth direction.

4. Both conduction and convection aspects of heat transfer must be considered in any attempt to achieve the desired planar interface shape in unidirectional solidification.

5. The bonds obtained in the hot pressing operations were unsatisfactory, hence, the procedure was unsatisfactory. There is no reason to believe that continued work in this area will not result in procedures which produce bond strengths which are commensurate with the strength of the matrix (5,000 psi. in tension (2)).

6. Deformation by hot pressing subsequent to unidirectional solidification produces a noticeable increase in the ultimate tensile strength of the material.



## VI. RECOMMENDATIONS

1. The results of this investigation coupled with work also being done at this time which has shown that, at temperatures above 300°C., the strength of the Al-Al<sub>3</sub>Ni unidirectionally solidified eutectic exceeds that of the best (2024-T6, 7075-T6, and 7178-T6) commercially available aluminum alloys definitely indicates that further research is warranted.

2. In the solidification of plate forms it is recommended that new apparatus be constructed with geometric symmetry from the heat conduction standpoint kept uppermost in all design considerations.

3. Research is needed in methods for restricting free convection in melts of significant size. Magnetic fields and high (180 - 240) amperage DC currents are suggested methods (9,11).

4. Concerning the plate lamination problem, it is recommended that consideration be given to the fabrication of male-female platens to restrict the deformation of the plates allowing the use of higher pressures.

5. The bond between the plates is a result of a diffusion process. Therefore, consideration should be given to accomplishing a more complete removal of the oxide layer and/or more time at temperature and pressure.

















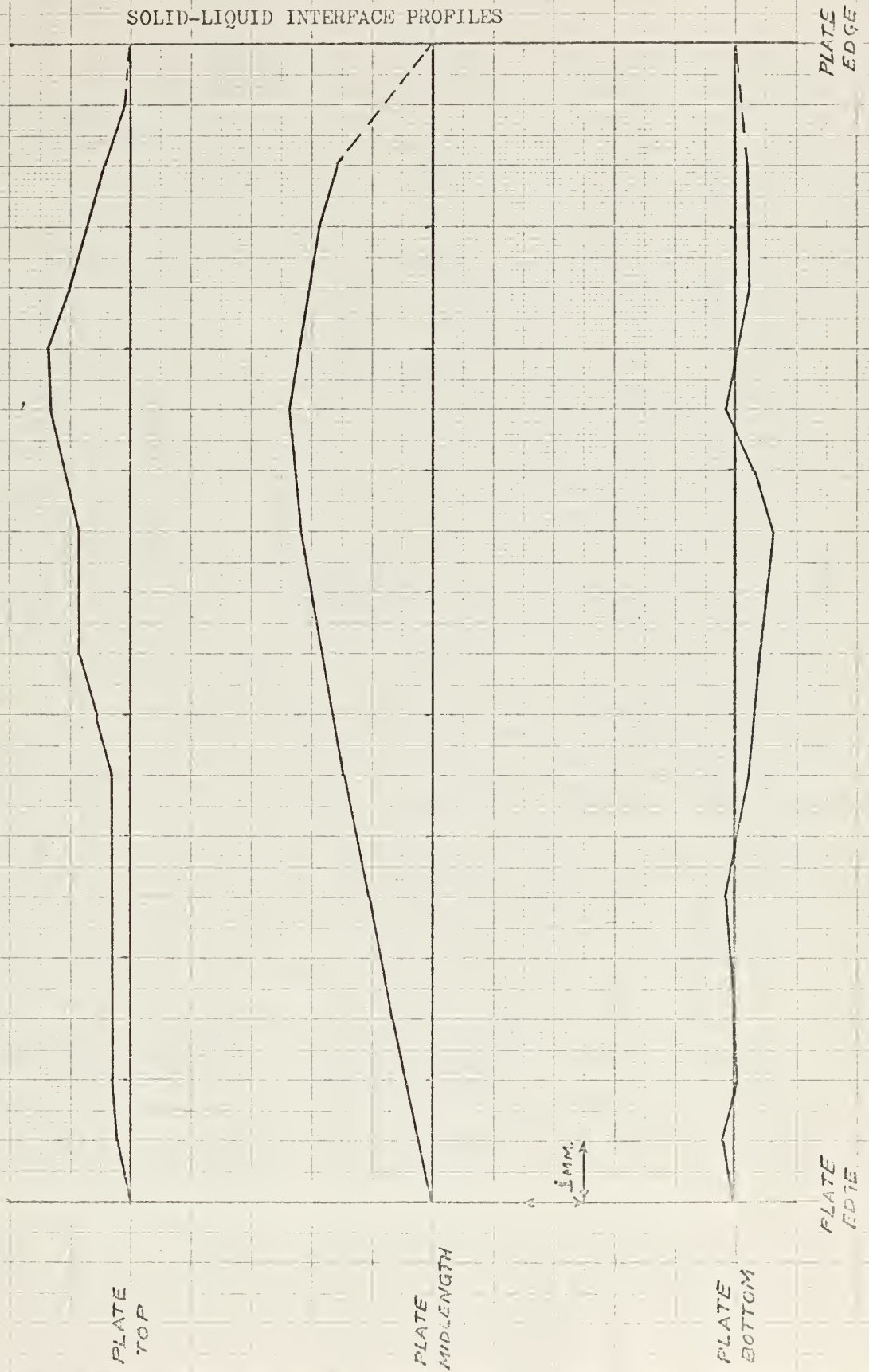








FIGURE VI  
SOLID-LIQUID INTERFACE PROFILES







APPENDIX



## DESCRIPTION OF APPARATUS

### Directional Solidification Furnace

This piece of apparatus was constructed by Lt. R. W. Render, USN, Lt. H. C. Lewis, USN, and the author especially for investigations of composite growth from the melt. It is pictured in Figure VII and diagrammed in Figure VIII (only one side of the circular furnace shown). Pertinent specifications follow:

Heating element:	2 sets of vertical coils mounted one atop the other. Rated capacity 9 amps @ 115 volts for each coil (1,000°C.).
Furnace box:	Vermiculite between stainless steel cylinder and heating element. Insulation jacket of 2 layers Al foil, 2 layers asbestos cloth, and 1 layer spun glass around cylinder. Transite spacer between heating element and Al end plates which are clamped with 3 through bolts (13 in. long).
Temperature controls:	Variac to control amperage. Thermocouple inserted into furnace wall (range 0 to 1,000°C.).
Furnace speed controls:	Variac controlling voltage to motor rated at 1,200 RPM @ 115 volts. Motor speed geared down to provide desired velocity in double chain hoist.



Furnace speed range: 2 to 10 cm/hr.

Atmosphere controls: Argon supply and vacuum line through two way valve into single line to glass tube containing specimen.

Special controls: Microswitch mounted on furnace frame - activated by furnace box at end of run to secure all power to motor and heater.

#### Graphite Mold

The mold used in casting and directional solidification is diagrammed in Figure IX.

#### Hot Press

See Figure VII. The press has a maximum capacity of 250,000 lbs. @ 1,000°F. with the temperature of each platen controlled separately. The top platen is fixed and the bottom platen moved by hydraulic pressure generated by an electric pump. Fine pressure variations are made with a double throw hand pump. The platens measure 14 x 20 in. with a maximum separation of 15 in.









FIGURE VIII.

## DIRECTIONAL SOLIDIFICATION FURNACE

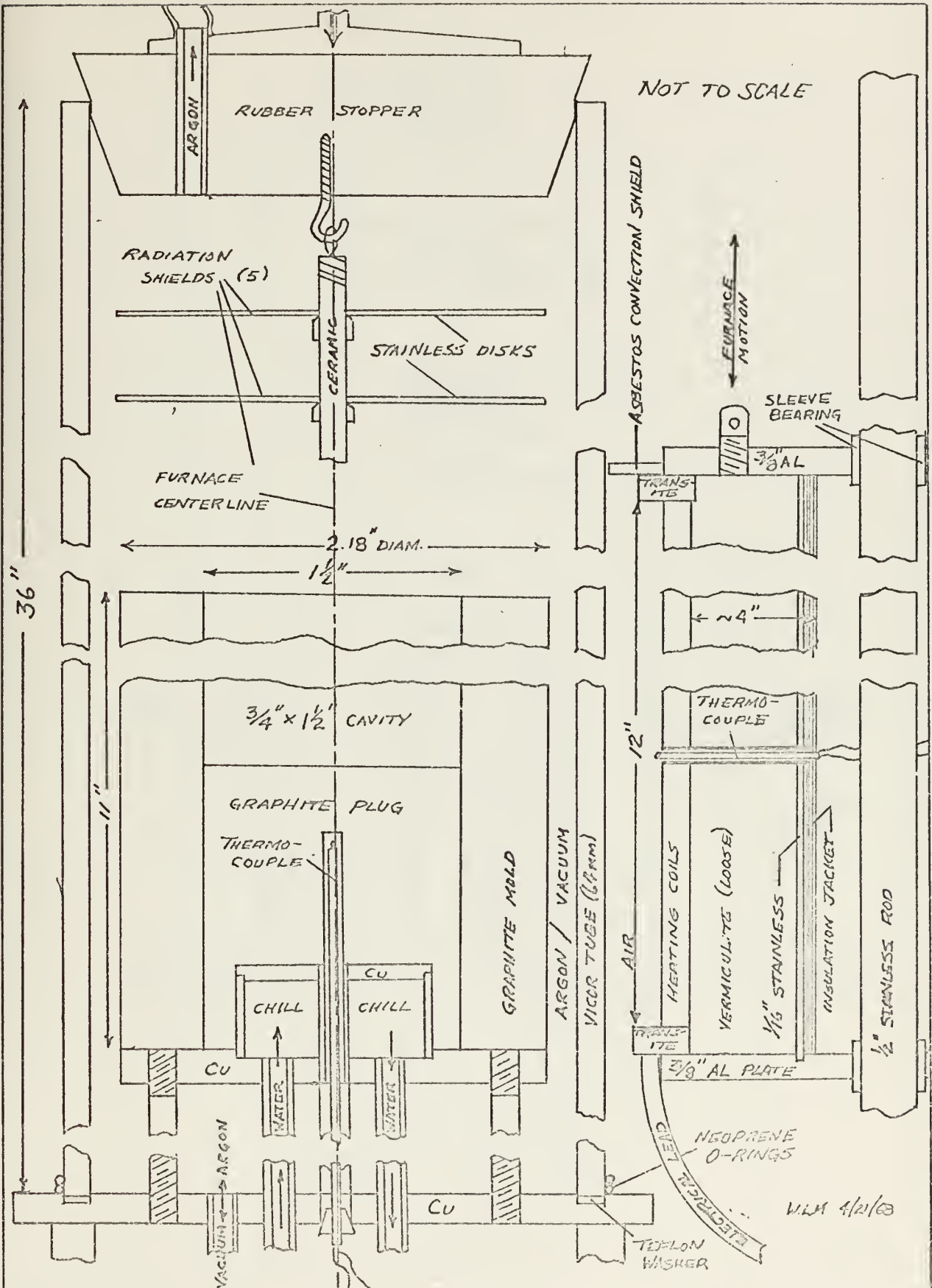
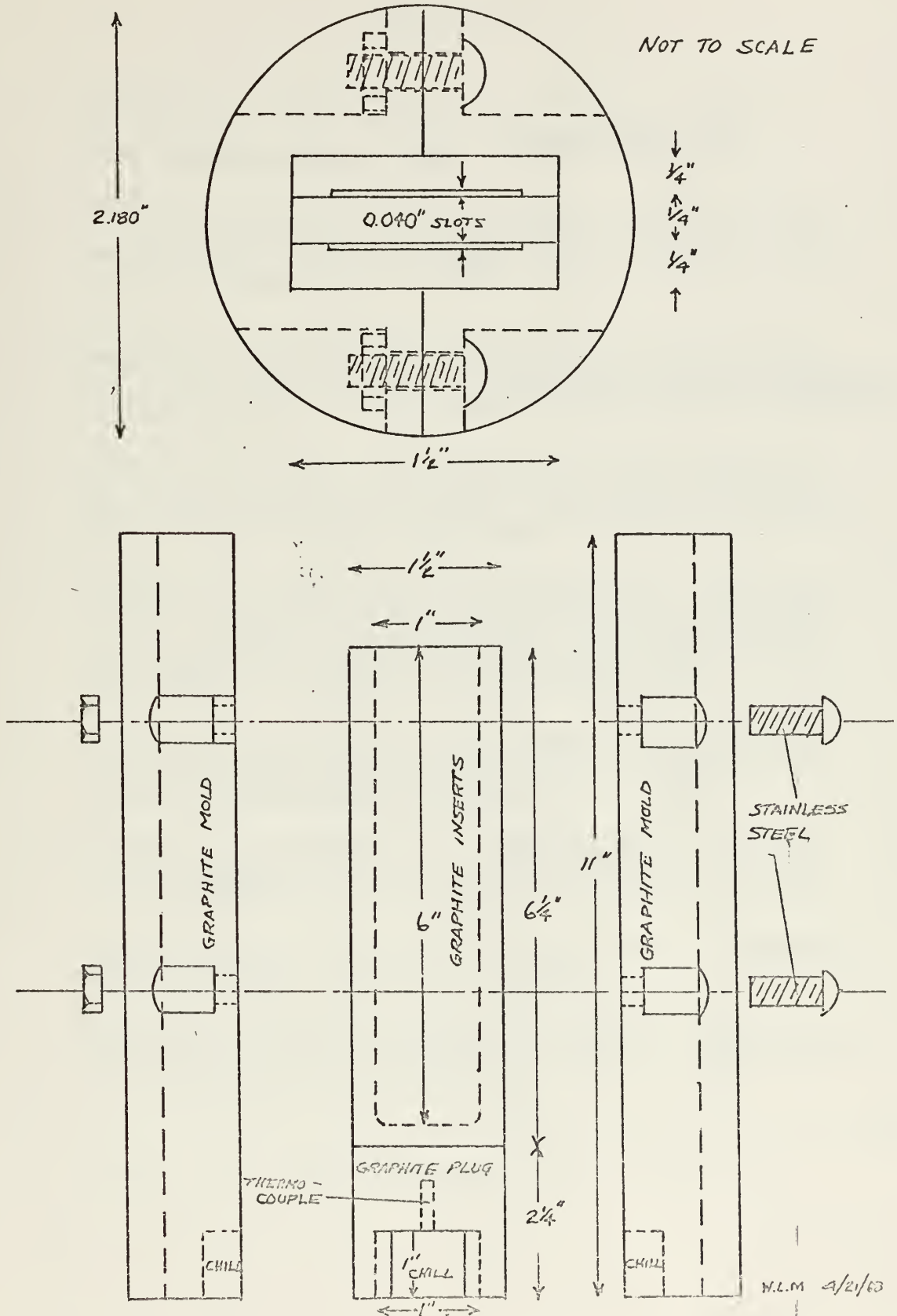




FIGURE IX.  
GRAPHITE MOLD





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